New b fragmentation measurements at LEP/SLD and their implications for Tevatron physics

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Overview

- b physics at the Tevatron
- b fragmentation measurements at LEP/SLD
- How is this related?

aim :

Demonstrate impact of the recent LEP/SLD b fragmentation measurements on Tevatron physics —
these measurements are not only relevant for old-fashioned e^+e^- colliders!

Overview

- b physics at the Tevatron
- b fragmentation measurements at LEP/SLD
- How is this related?

Disclaimer:
KH $\in$ D0 masthead
KH $\notin$ D0 author list
Guess why?
The statements on Tevatron physics in this talk are outside non-expert views!
Important oversights, misconceptions etc. are to be expected!

b Physics at the Tevatron

- CP violation (B_s!)
- rare decays
- lifetimes/mixing
- cross-sections
- spectroscopy

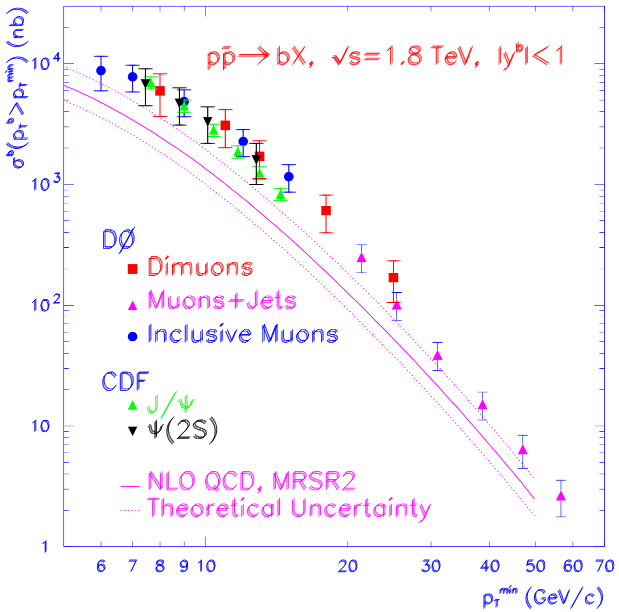
PLUS: b physics as a tool for “heavier” topics

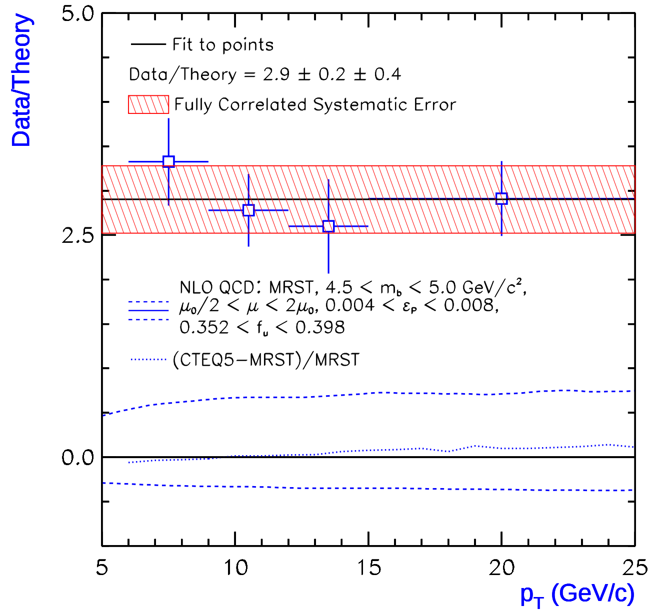
- top
- Higgs
- SUSY

How can LEP/SLD measurements help?

Impact of LEP/SLD physics on the Tevatron

Example: b production cross-section as measured in Tevatron Run I (left: D0 and CDF; right: CDF, hep-ph/0111359):



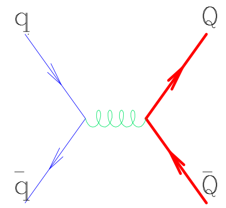


Is this new physics or a systematic bias?

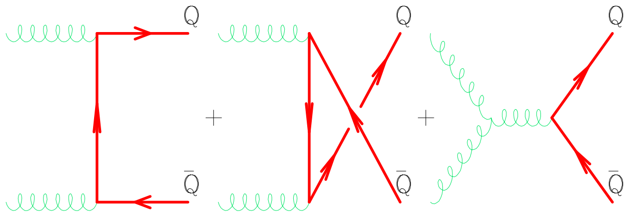
➡ LEP/SLD can help to understand this due to simpler event structure

Impact of LEP/SLD physics on the Tevatron

Prediction of b production cross-section at the Tevatron:



(a)



(b)

- Structure functions $\longrightarrow$ specific number of b's at specific energy
- Hadronisation effects $\longrightarrow$ shift b energies downward
- Efficiency $\longrightarrow$ usually depends on energy distribution!

Impact of LEP/SLD physics on the Tevatron

- Structure functions $\longrightarrow$ specific number of b's at specific energy
- Efficiency $\longrightarrow$ usually depends on energy distribution!

These two are collider-/detector-specific. No good topic for this talk.

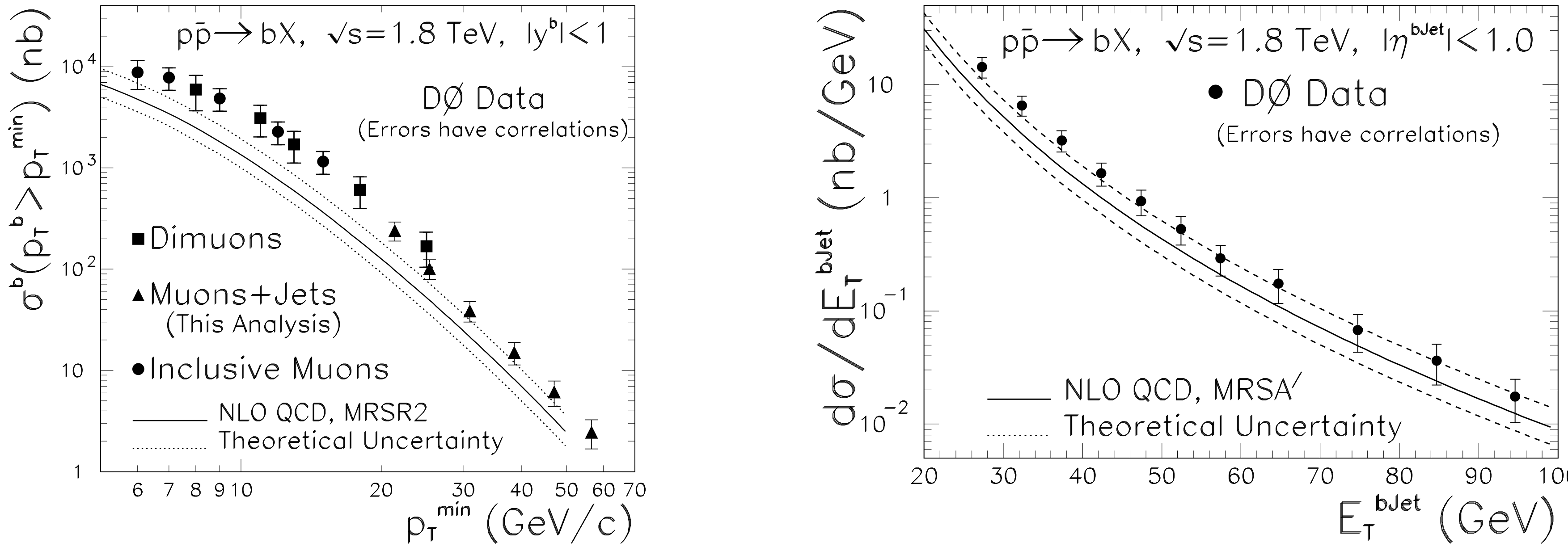
Impact of LEP/SLD physics on the Tevatron

★ Hadronisation effects $\longrightarrow$ shift b energies downward

This is presumed to be universal! Let LEP/SLD help.

Impact of LEP/SLD physics on the Tevatron

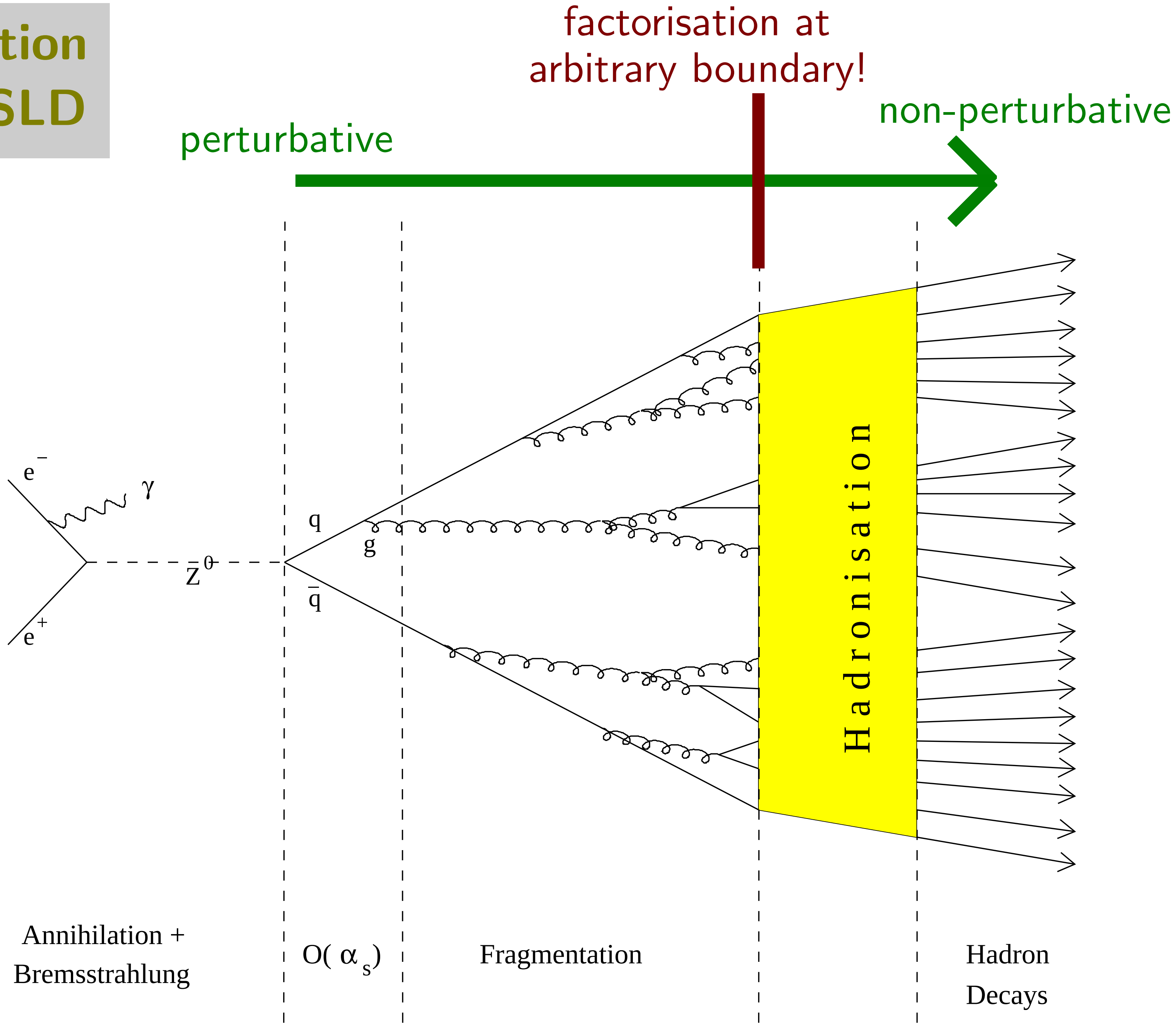
If hadronization effects are a problem,
the cross-section over the jet momentum should show better agreement than the cross-section over the b hadron momentum.



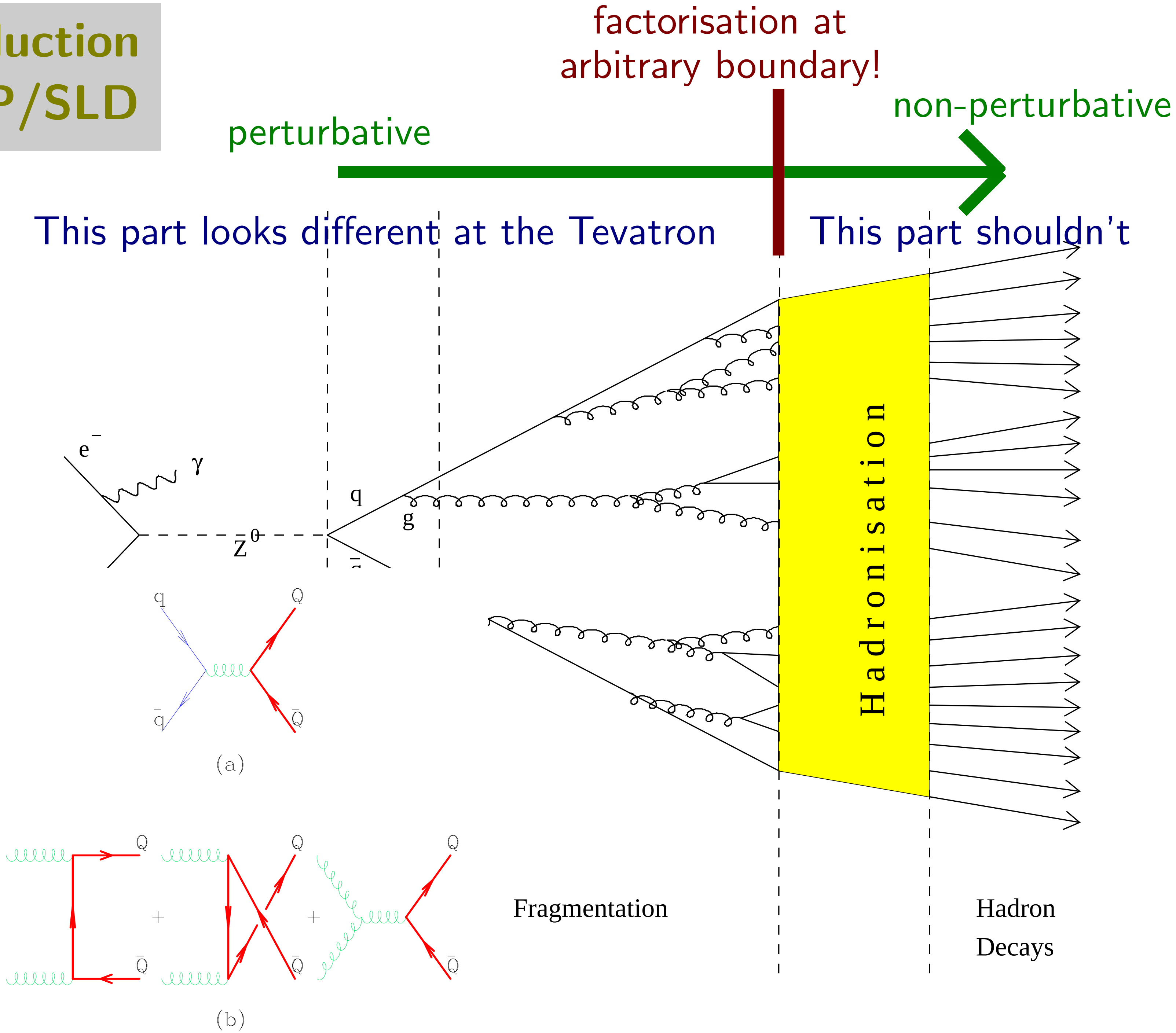
This seems to be the case! $\longrightarrow$ look at LEP/SLD

D0, hep-ex/0008021

b production at LEP/SLD



b production at LEP/SLD

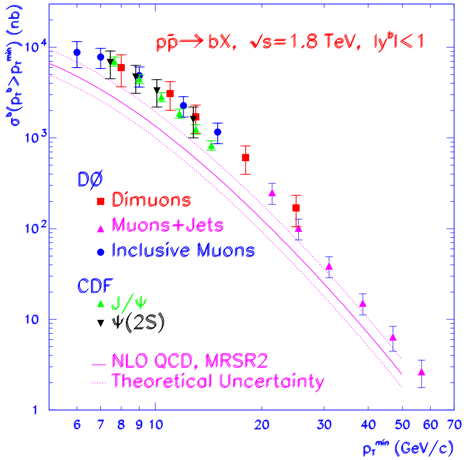


PLAN

- constrain hadronisation at LEP/SLD
- plug results into models for the Tevatron
- see what happens

This has been done before!

Old and very simple measurements, only part of the LEP/SLD dataset



...maybe we should try again?

LEP/SLD did it again!

New round of b fragmentation/hadronisation measurements 2000–2003

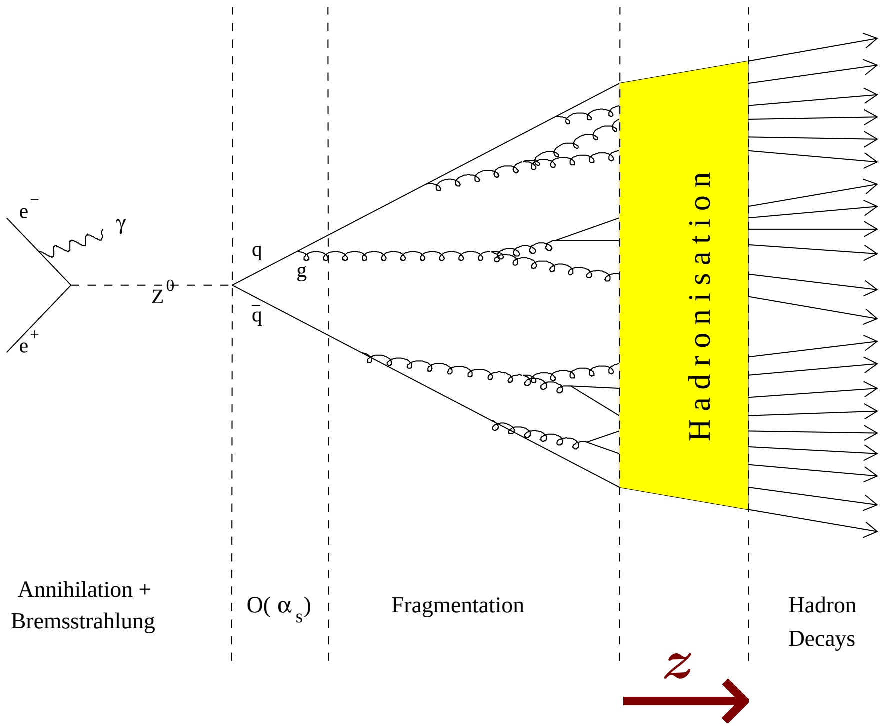
Use as input for Tevatron physics is only one benefit.
True egoistic motivation:

- hadronisation effects are huge systematic uncertainty at LEP/SLD
- understanding the origin of mass!

non-perturbative QCD accounts for almost all visible mass in the universe, not the Higgs!

Quantitative description of hadronisation

consider energy fraction transferred from quark to hadron



hadronisation models describe $f(z)$:

$$z = \frac{\text{energy of primary hadron}}{\text{energy of quark prior to hadronisation}}$$

model-dependent, not a nice observable!

$f(z)$: fragmentation functions (should be: "hadronisation functions")

Peterson et al. $f(z) \propto \frac{1}{z(1-\frac{1}{z}-\frac{\varepsilon}{1-z})^2}$

$\longrightarrow$ estimation of transition matrix element by energy difference

Collins/Spiller $f(z) \propto (\frac{1-z}{z} + \frac{(2-z)\varepsilon}{1-z})(1+z^2)(1-\frac{1}{z}-\frac{\varepsilon}{1-z})^{-2}$

$\longrightarrow$ from correspondence to heavy meson structure functions

Kartvelishvili et al. $f(z) \propto z^{\alpha}(1-z)$

$\longrightarrow$ from correspondence to different model of heavy meson structure functions

Lund symmetric $f(z) \propto \frac{1}{z}(1-z)^a \exp(-\frac{bm_t^2}{z})$

$\longrightarrow$ symmetry wrt. start of string hadronisation at either end of the string

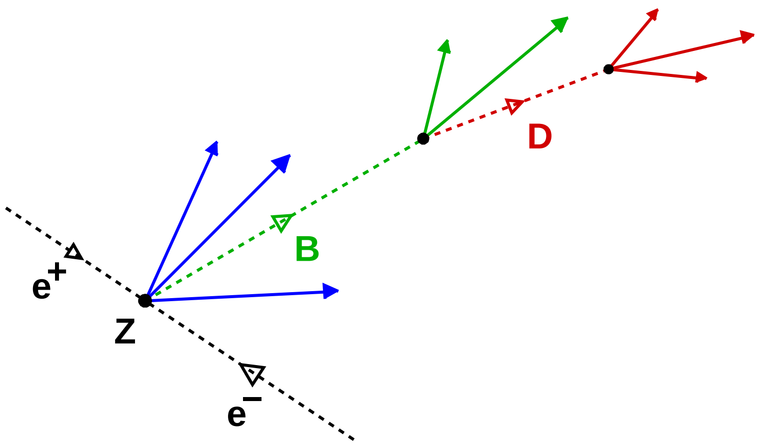
Bowler $f(z) \propto \frac{1}{z^{1+bm_t^2}}(1-z)^a \exp(-\frac{bm_t^2}{z})$

$\longrightarrow$ constant probability per length and time for $q\overline{q}$ creation on the string

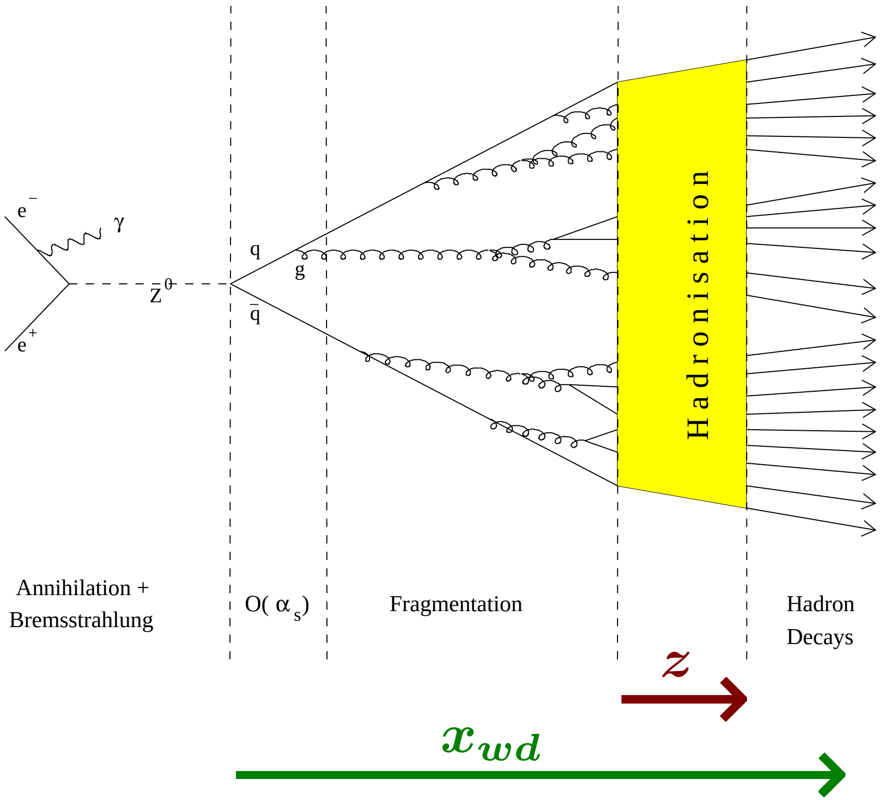
$z = \frac{\text{energy of primary hadron}}{\text{energy of quark prior to hadronisation}}$ not directly measureable:

– energy of quark prior to hadronisation (*after* fragmentation) not observable

– further problem: b hadron easily identified in weak decay (lifetime, mass)
but: weakly decaying hadron $\neq$ primary hadron
frequent creation of excited hadrons + cascade decays



Alternative variable: x_{wd}



$$z = \frac{\text{energy of primary hadron}}{\text{energy of quark prior to hadronisation}}$$

replace:

primary hadron
$\longrightarrow$ weakly decaying hadron

quark energy prior to hadronisation
$\longrightarrow$ energy at $q\bar{q}$ creation
(at 90 GeV: $\approx$ beam energy)

$$\boxed{x_{wd} = \frac{\text{energy of weakly decaying hadron}}{\text{beam energy}}}$$

"scaled energy"

measure energy distribution of weakly decaying hadrons
correspondence to hadronisation model: Monte Carlo

Typical measurements of the B hadron energy distribution

reconstructed B hadrons	data sample	energy resolution
exclusive semileptonic decays (B$\longrightarrow$D$^{(*)}\boldsymbol{\ell\nu}$)	small	$\approx \mathbf{5\%}$
inclusive semileptonic decays (B$\longrightarrow$ $\boldsymbol{\ell}$+X)	large	$> \mathbf{10\%}$
inclusive (decay vertices etc.)	very large	$\approx \mathbf{10\%}$

total number of B hadrons created at LEP: $\approx$ 2 million per experiment
SLD: $\approx$ 0.2 million
(TESLA GigaZ: several 100 million)

examples: recent measurements of the mean scaled energy $\langle \boldsymbol{x_{wd}} \rangle$:

B$\longrightarrow$D$^{(*)}\boldsymbol{\ell\nu}$	ALEPH 2001	$\langle \boldsymbol{x_{wd}} \rangle = \mathbf{0.716 \pm 0.006}(\boldsymbol{stat}) \pm \mathbf{0.006}(\boldsymbol{syst})$
B$\longrightarrow$ $\boldsymbol{\ell}$+X	OPAL 1999	$\langle \boldsymbol{x_{wd}} \rangle = \mathbf{0.709 \pm 0.003}(\boldsymbol{stat}) \pm \mathbf{0.013}(\boldsymbol{syst})$
inclusive	SLD 2002	$\langle \boldsymbol{x_{wd}} \rangle = \mathbf{0.709 \pm 0.003}(\boldsymbol{stat}) \pm \mathbf{0.004}(\boldsymbol{syst})$

LEP/SLD b fragmentation analyses

To be presented here:

ALEPH: Phys. Lett. **B512** (2001) 30.
SLD: Phys. Rev. **D66** (2002) 092006, Erratum ibid. **D66** (2002) 079905.
OPAL: hep-ex/0210031, submitted to Eur. Phys. J. C
DELPHI: DELPHI 2002-069 CONF 603. (preliminary)

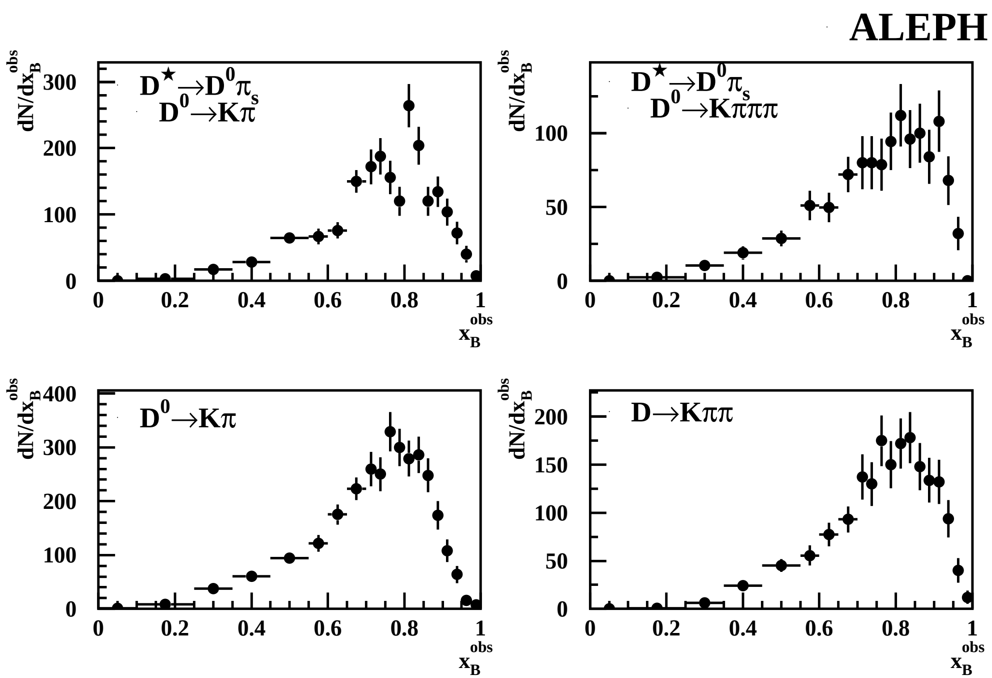
ALEPH: B meson reconstruction

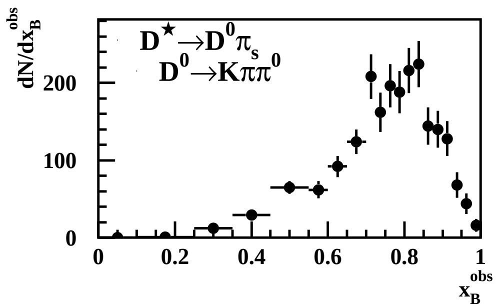
exclusive B meson decays:
$\mathrm{B} \longrightarrow \mathrm{D}^{(*)}\boldsymbol{\ell\nu}$

- $\boldsymbol{\ell}$: either e or $\boldsymbol{\mu}$
- five $\mathrm{D}^{(*)}$ channels:

  $\mathrm{D}^{*+}\!\longrightarrow \mathrm{D}^0\boldsymbol{\pi}^+,$
  $\quad\hookrightarrow \mathrm{K}^-\boldsymbol{\pi}^+$
  $\quad\hookrightarrow \mathrm{K}^-\boldsymbol{\pi}^+\boldsymbol{\pi}^+\boldsymbol{\pi}^-$
  $\quad\hookrightarrow \mathrm{K}^-\boldsymbol{\pi}^+\boldsymbol{\pi}^0$
  $\mathrm{D}^+ \longrightarrow \mathrm{K}^-\boldsymbol{\pi}^+\boldsymbol{\pi}^+$
  $\mathrm{D}^0 \longrightarrow \mathrm{K}^-\boldsymbol{\pi}^+$
- $\boldsymbol{\nu}$ energy := missing energy

B energy resolution: 3–5%
≈3400 candidates



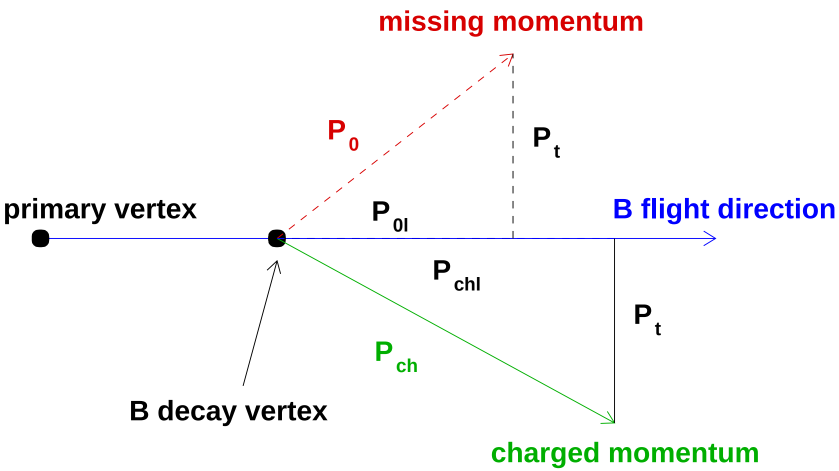


distribution of uncorrected scaled energy x_{wd}^{rec}

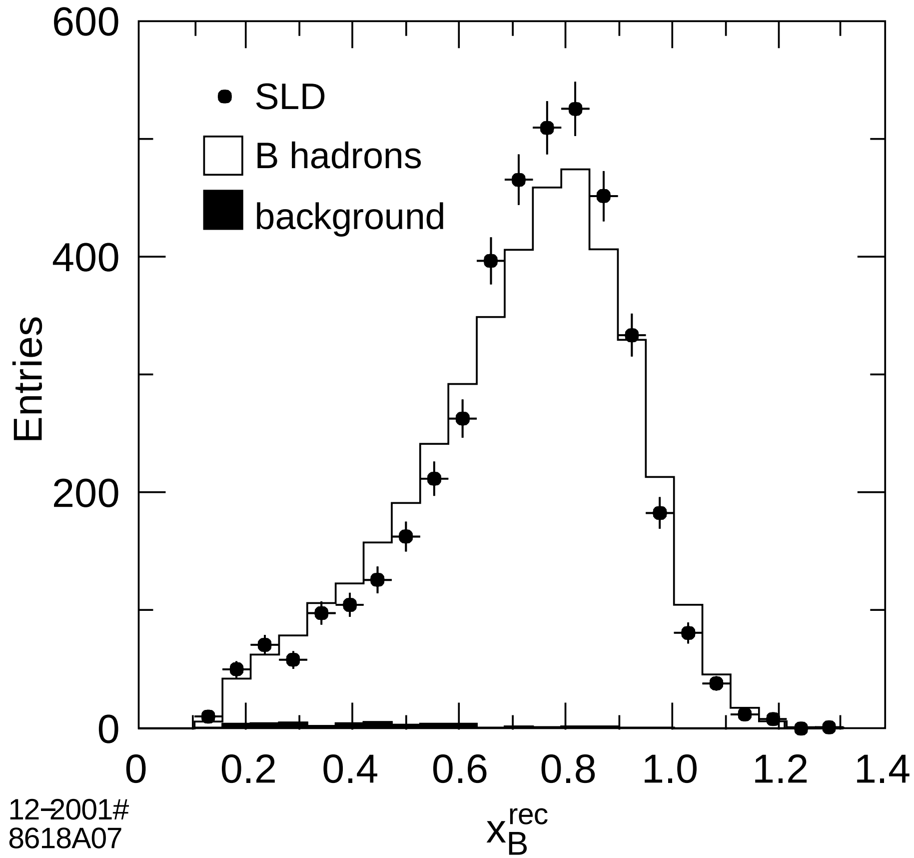
SLD: inclusive B hadron reconstruction

SLD

inclusive B energy reconstruction
from vertex flight direction
and charged B decay products



B energy resolution: 10%
≈4200 candidates



uncorrected scaled energy x_{wd}^{rec}

DELPHI, OPAL: inclusive B hadron reconstruction

inclusively identify and reconstruct

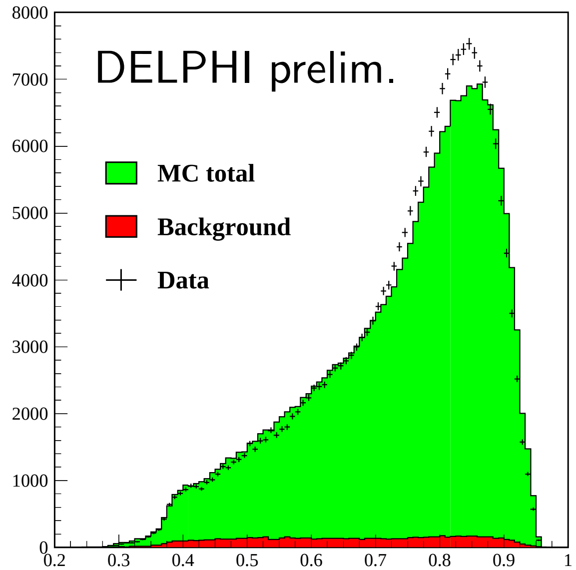
B hadrons from

- weak B hadron decay vertices
- leptons from weak B hadron decay
- charged and neutral decay products

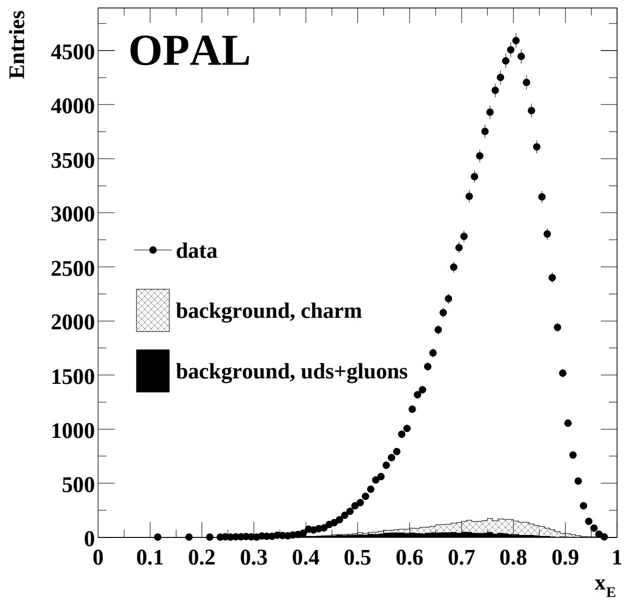
using Artifical Neural Nets, Likelihoods

(OPAL: x_{wd}^{rec}; DELPHI: x_{wd}^{rec}, x_L^{rec}, z^{rec})

DELPHI: B energy resolution: $\mathcal{O}(10\%)$
$\approx$230,000 candidates
OPAL: B energy resolution: $\mathcal{O}(10\%)$
$\approx$270,000 candidates

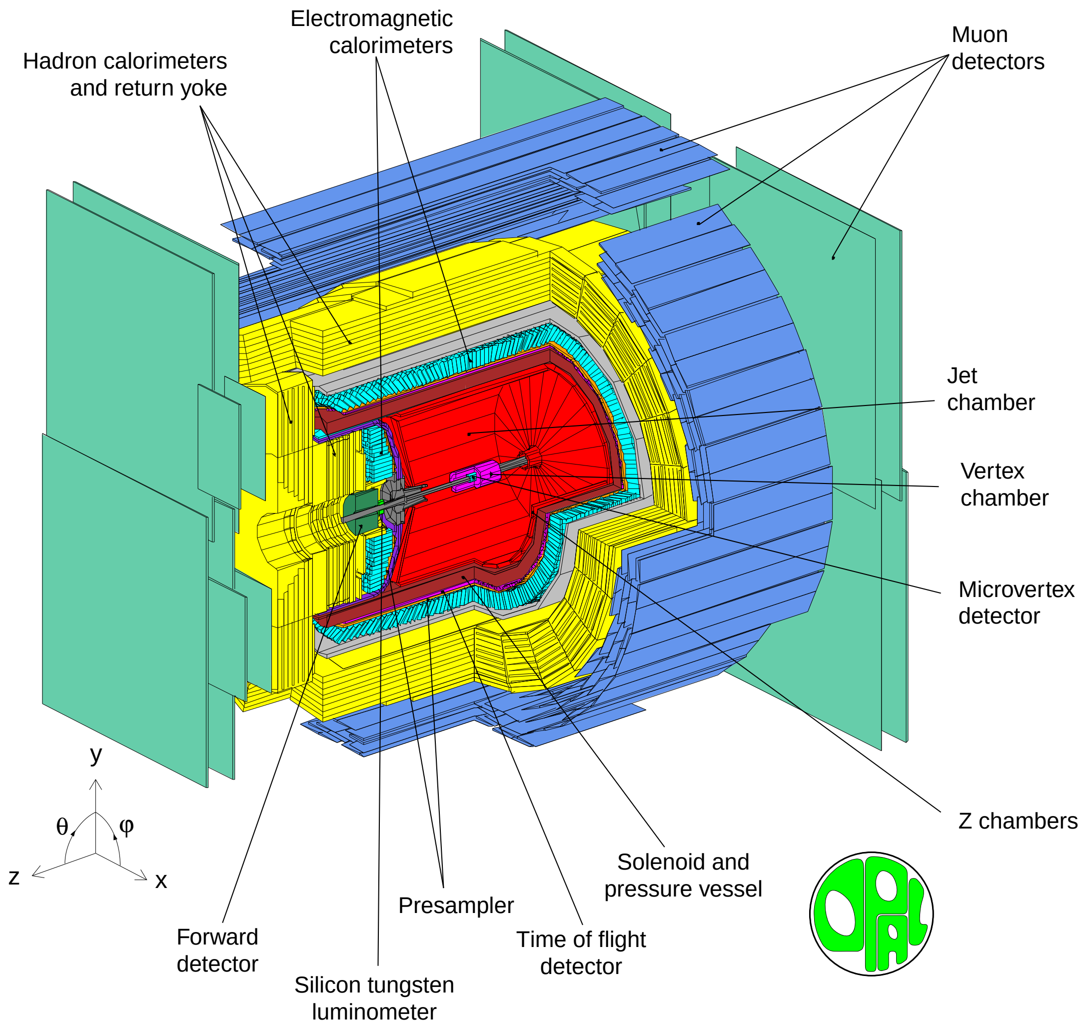


x_{wd}^{rec}



x_{wd}^{rec}

Example: OPAL



vertex detector hit resolution

$\mathbf{10-15}\,\boldsymbol{\mu}\mathrm{m}$

momentum resolution

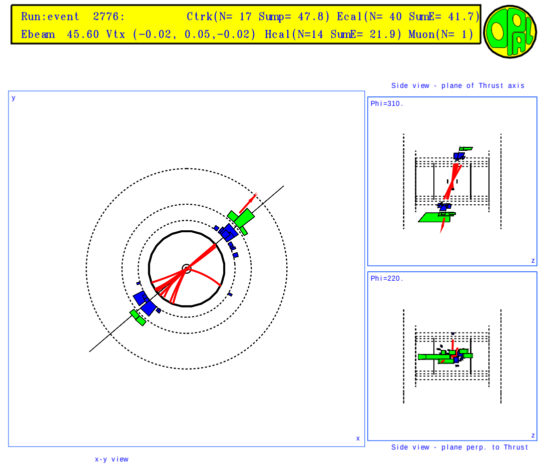
$\approx \mathbf{1.1} \times \mathbf{10^{-3}}(\mathrm{GeV})^{\mathbf{-1}}$

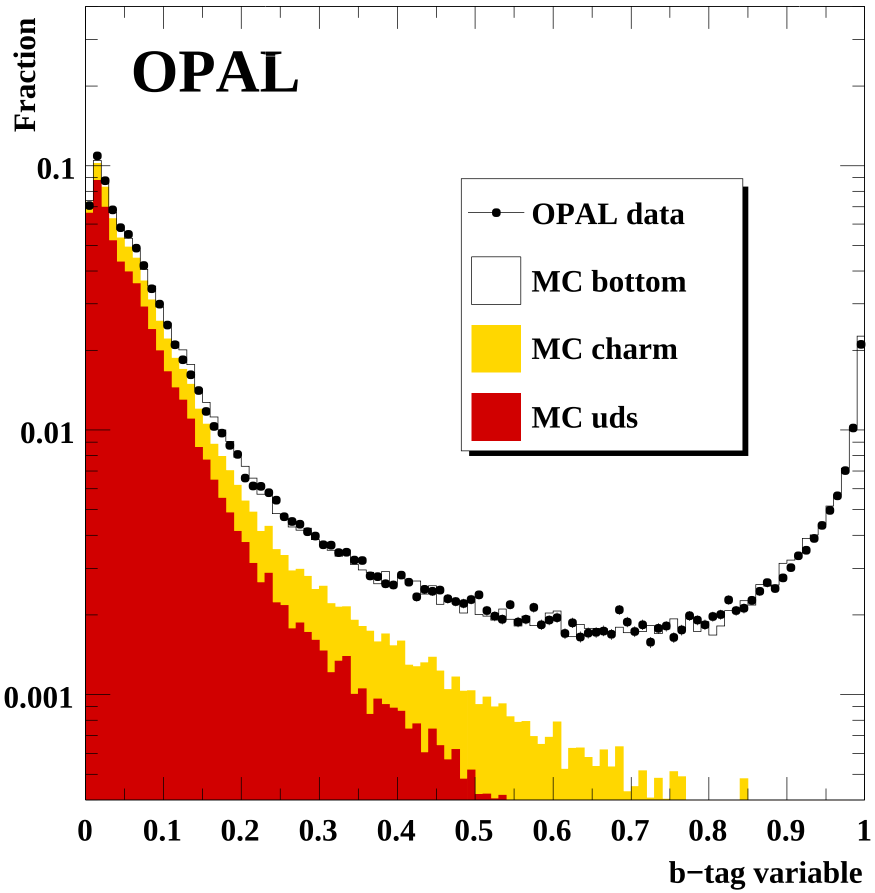
jet energy resolution

$\approx \mathbf{95\%}/\sqrt{\boldsymbol{E}}$

Selection and reconstruction of B hadrons

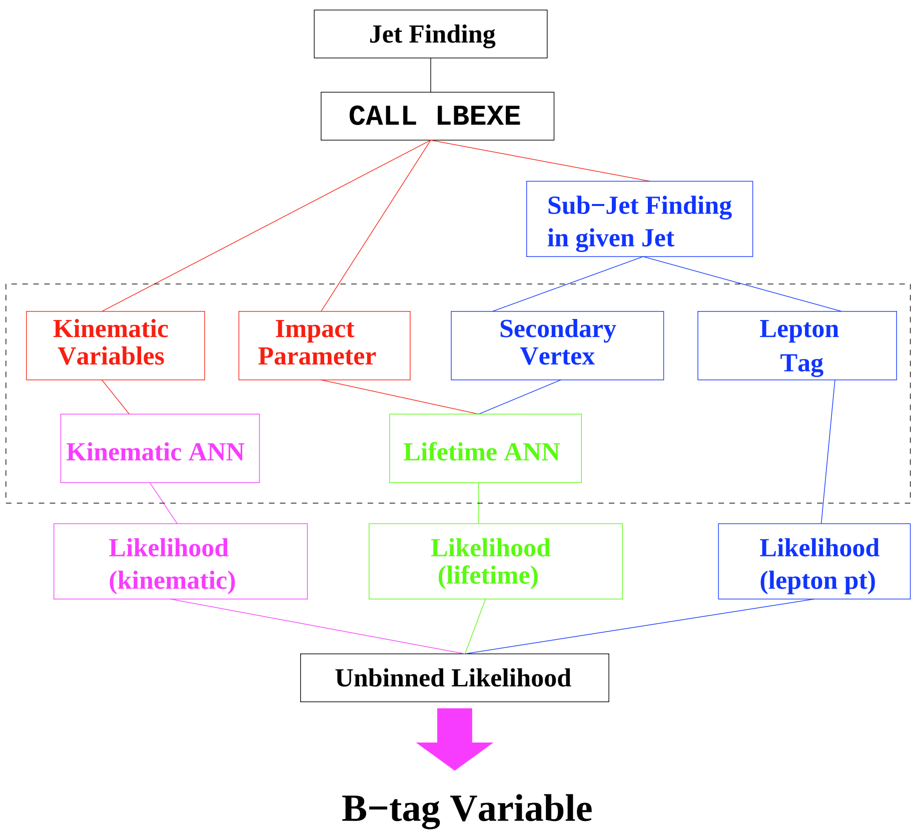
- selection of b jets
- reconstruction of B decay vertex
- selection of B hadron decay products
  artificial neural nets identify tracks and clusters from B decays
- estimation of the B hadron energy
  weighted sum over all selected
  tracks and clusters (weight = ANN output)

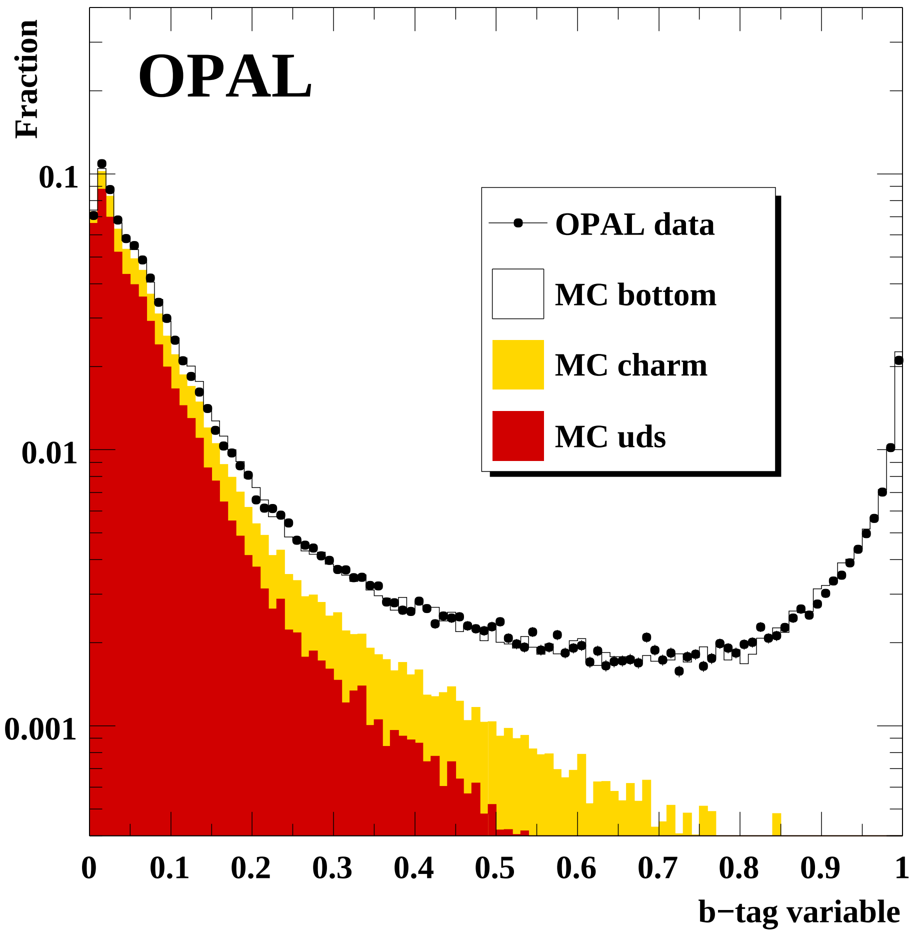




reconstruction efficiency: 16%
background contamination: 4%
energy resolution ≈ 10%

Jet-wise b-tag à la OPAL Higgs searches

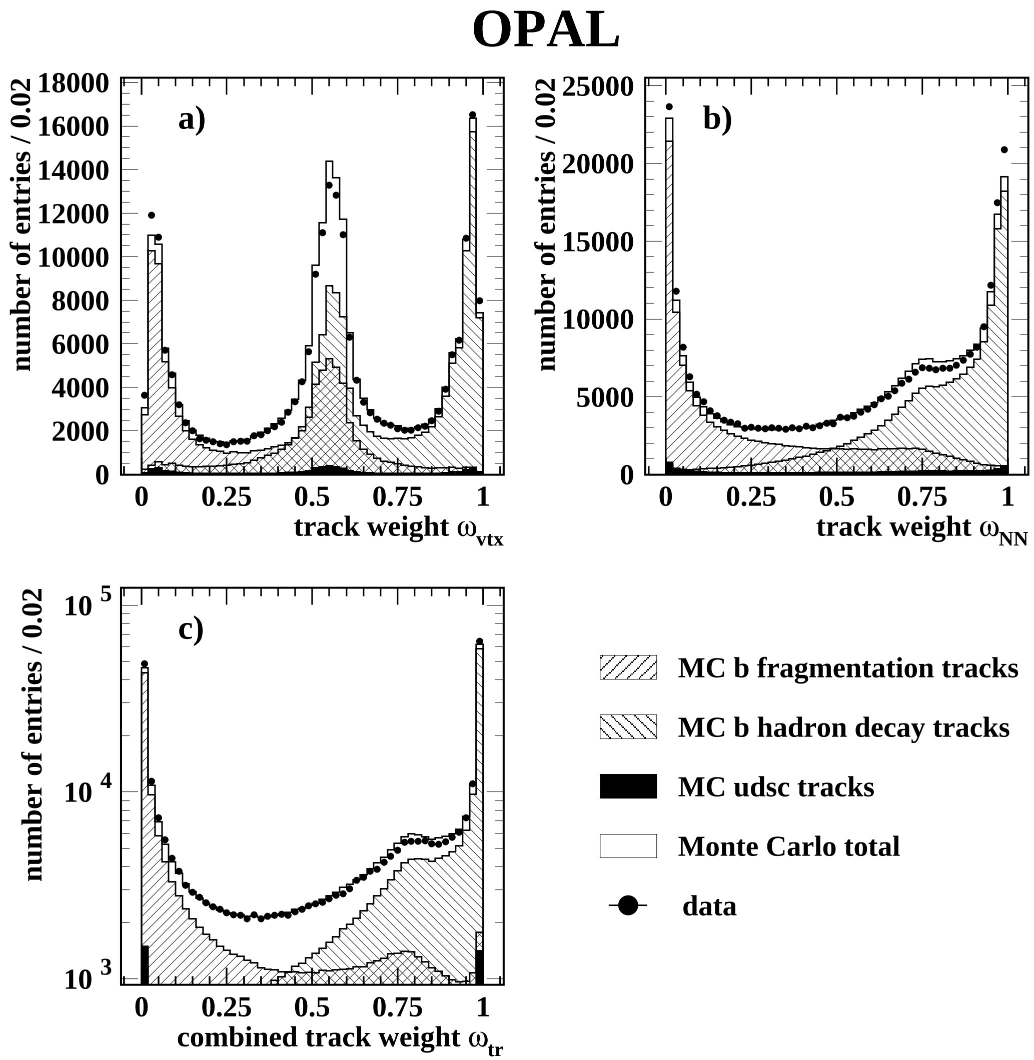




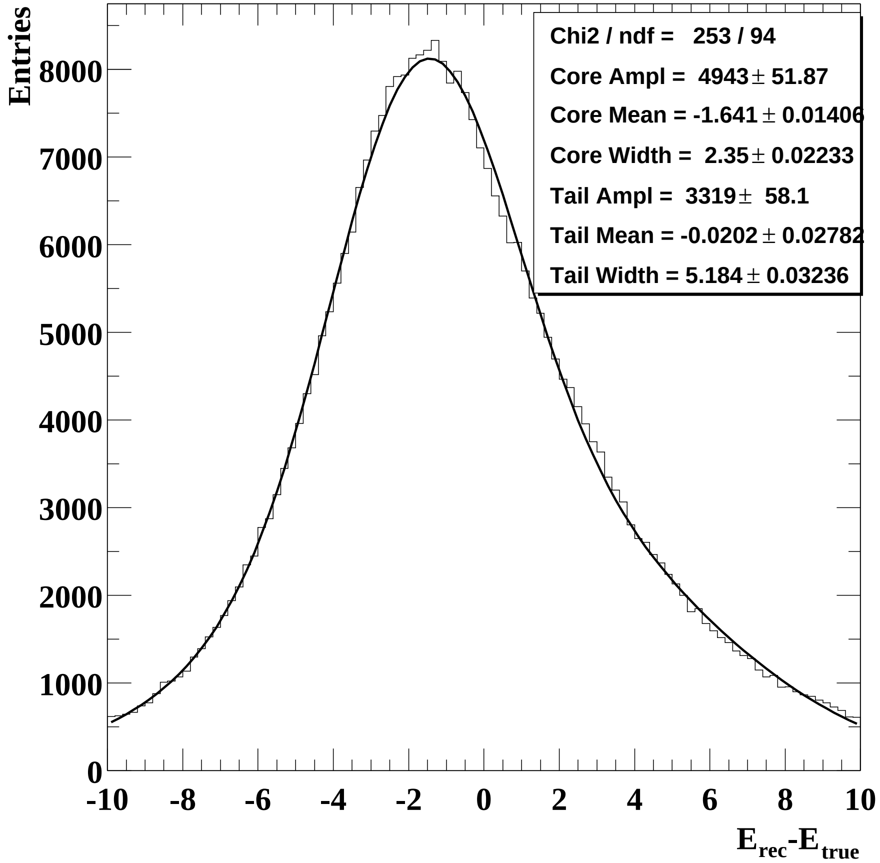
Track and cluster weight calculation

neural nets calculate
B hadron weights
for each track and cluster
in the hemisphere
defined by the jet axis

(Figure from
Michael Thiergen)



Energy resolution



good measurement of the B hadron energy

sensitive to hadronisation models

comparison of models with data:

- tune important Monte Carlo parameters to data
- reweight $f(z)$ in Monte Carlo to desired fragmentation function
- fit fragmentation function parameters to data

Energy distribution $\Longleftrightarrow$ hadronisation models

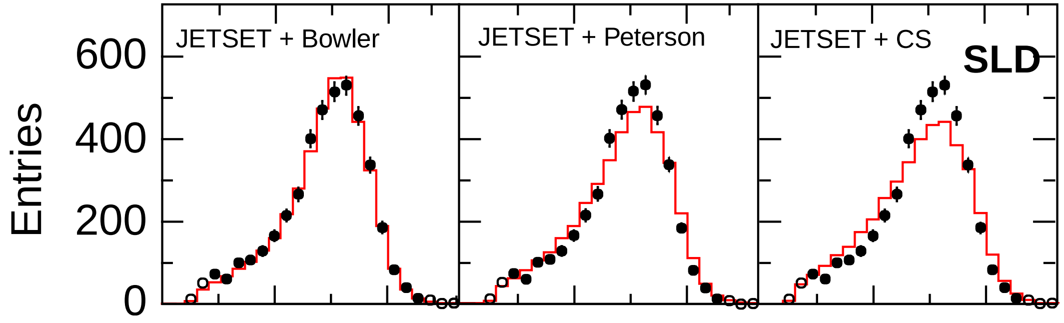
two main methods to derive information about hadronisation
from the hadron energy distribution:

- comparison of x_{wd} distribution with model predictions
- determination of model-independent parameters of the x_{wd} distribution
  e.g. mean scaled energy, $\langle x_{wd} \rangle$

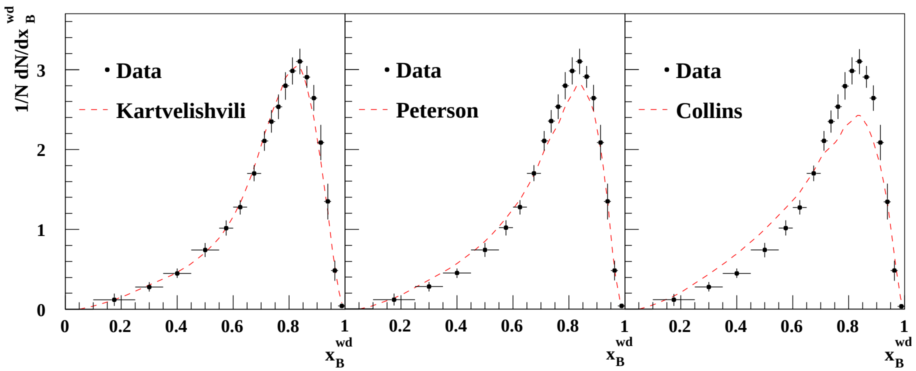
both methods used in all presented analyses

Results of model tests

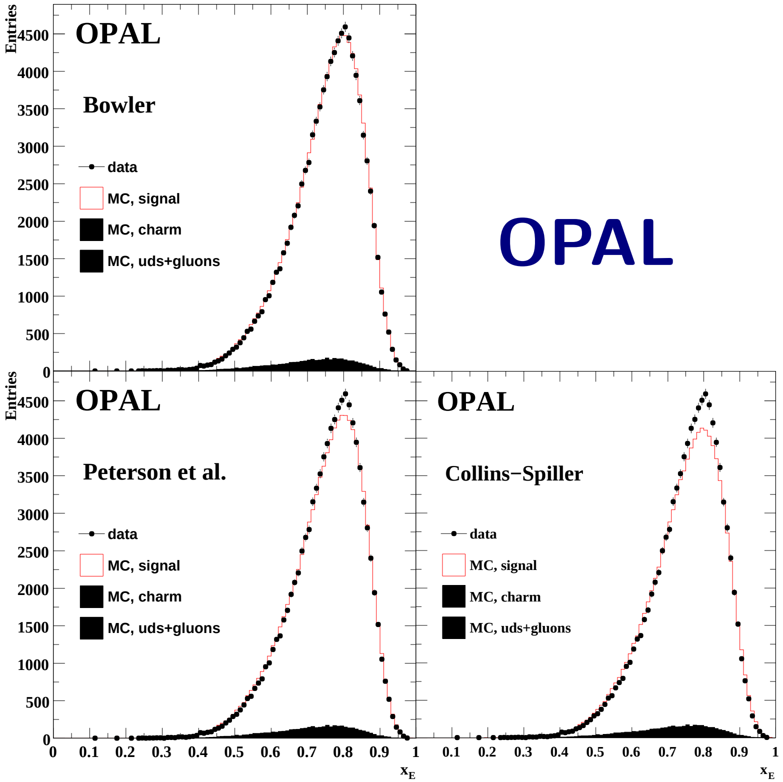
SLD



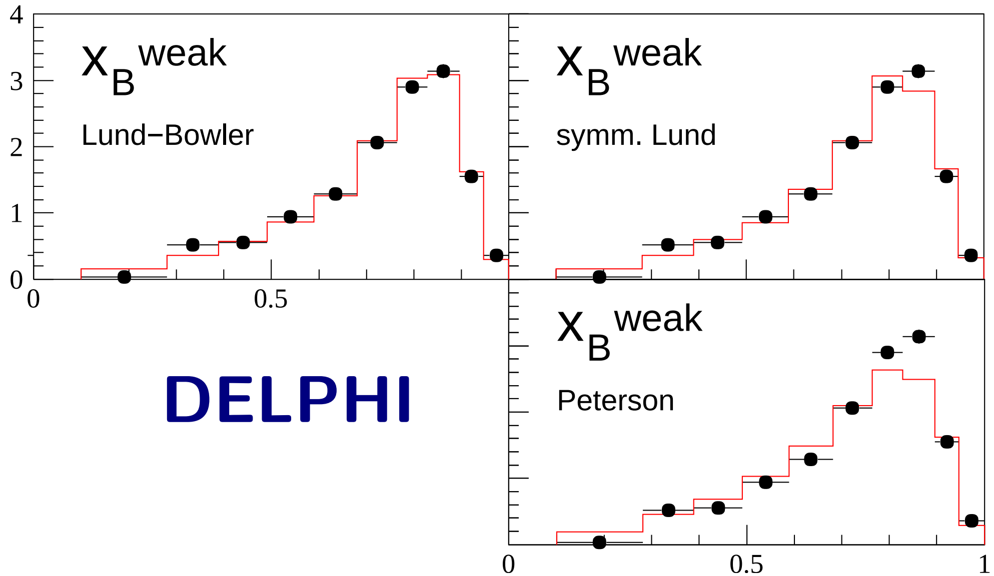
ALEPH



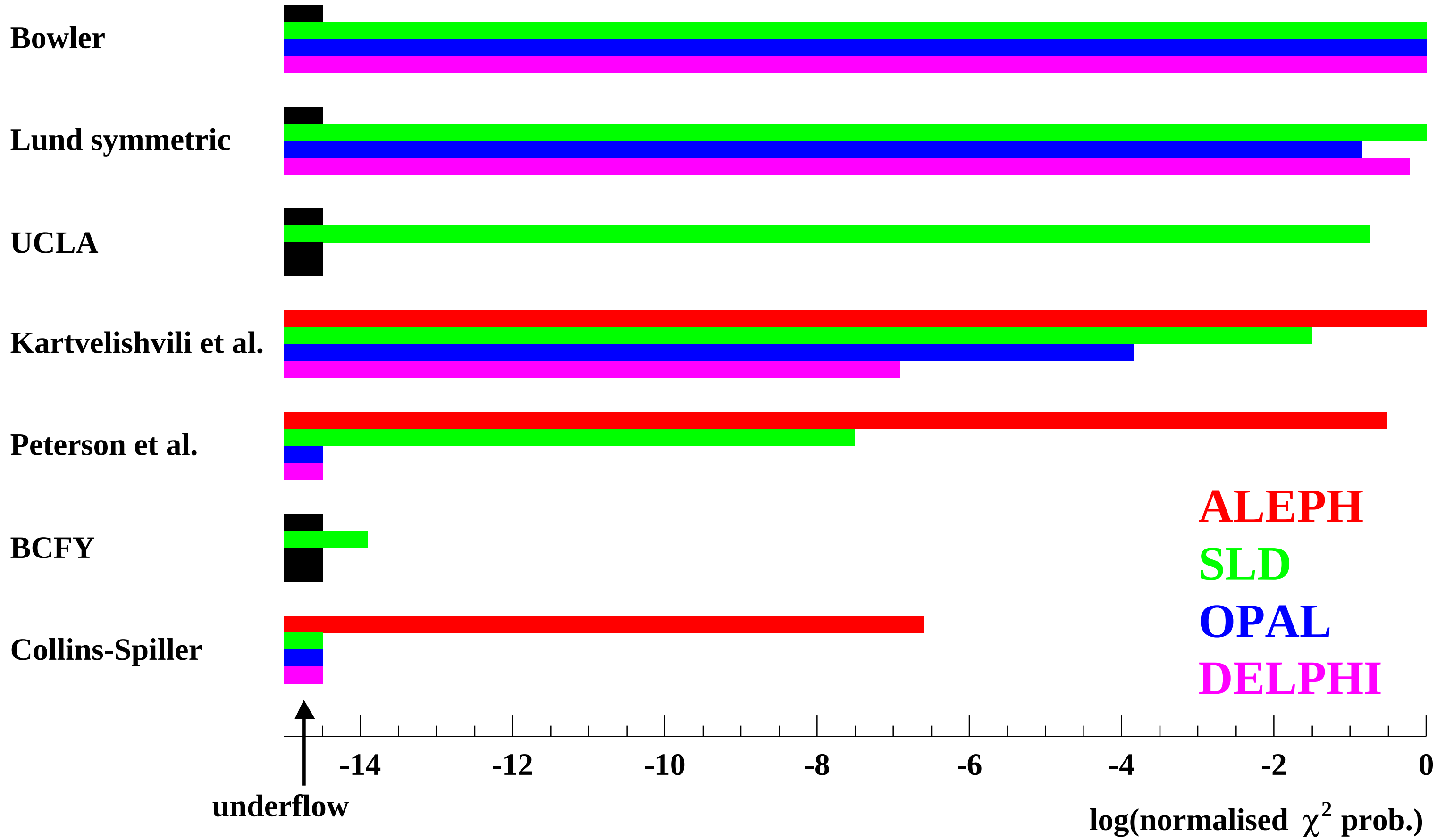
OPAL



DELPHI



LEP/SLD 2001/2002: normalized χ^2/d.o.f. probabilities



same ranking seen by all experiments!!! Herwig 5/6: tested by OPAL+SLD, but disfavored

THIS IS IMPORTANT INPUT FOR QCD STUDIES!

Problems with model-dependent energy spectrum fits

Fragmentation function parameters for specific models

- provide insufficient information for future model-builders
- depend strongly on (perturbative) fragmentation setup in MC

  $\longrightarrow$ difficult to transfer results to e.g. hadron collider MC

  but this is how it was done for Run I b cross-section measurements!

even worse:

look at description of B hadron energy distribution $D(x)$ in terms of moments

$$D_i = \int_0^1 dx\; x^{i-1} D(x)$$

$D_1 = 1$, $D_2 = \langle x_{wd} \rangle$

Problems with model-dependent energy spectrum fits

Model-dependent fragmentation function fits give good description of
D_2 (mean),
D_3 (width) of the spectrum
Modelling of higher moments is usually BAD!
Hadron colliders: $D_{4\pm1}$ most important

do NOT fit parameters like Peterson ε and use them in hadron collider MC

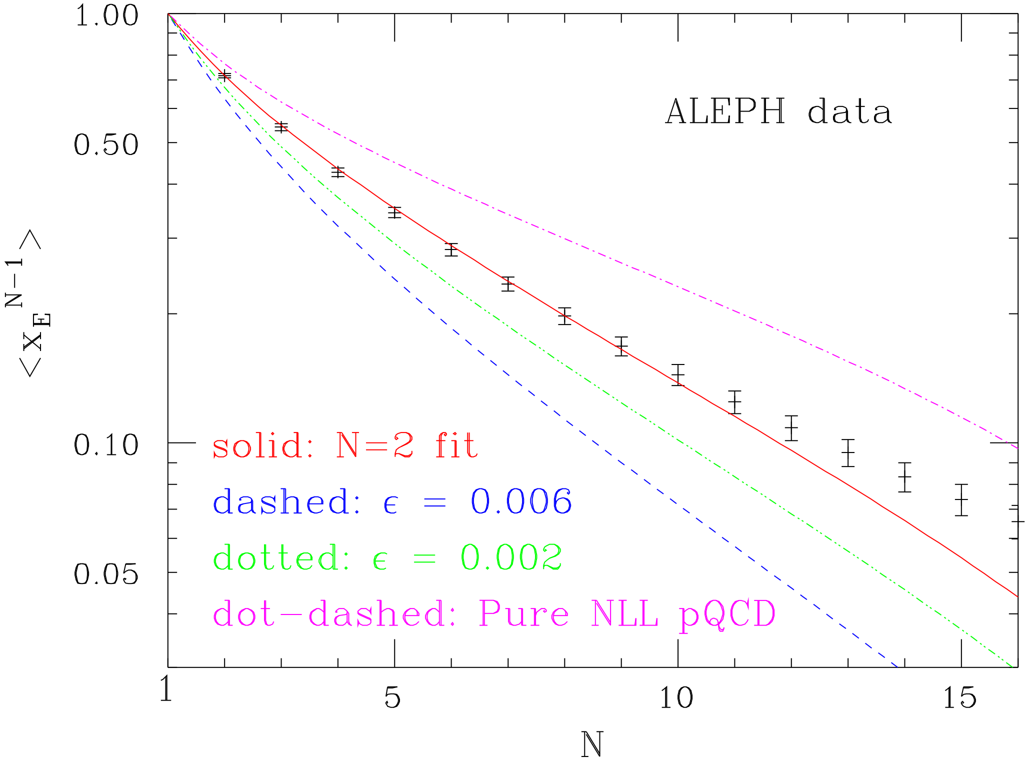
...but this is how it was done for Run I b cross-section measurements!

instead:
LEP/SLD have to provide model-independent measurement of higher moments

$$D_i = \int_0^1 dx\, x^{i-1} D(x)$$

Hadronisation tuning for the Tevatron

fit hadronisation parameters to moments, not to x_{wd} shape



(M. Cacciari, hep-ph/0205326; "N=2 fit" using Kartvelishvili et al.)

Would you experimentalists please *finally* provide us with model-independent measurements of higher moments of the B hadron energy spectrum?!?

M. Cacciari

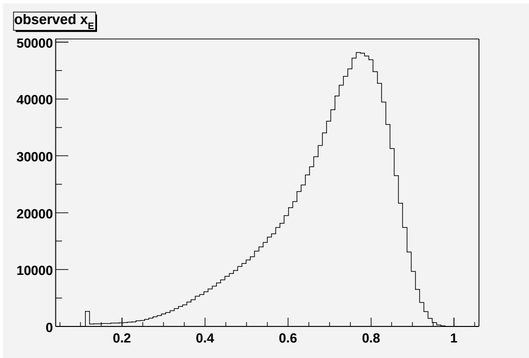
Well, we (ALEPH, DELPHI, OPAL, SLD) did ...

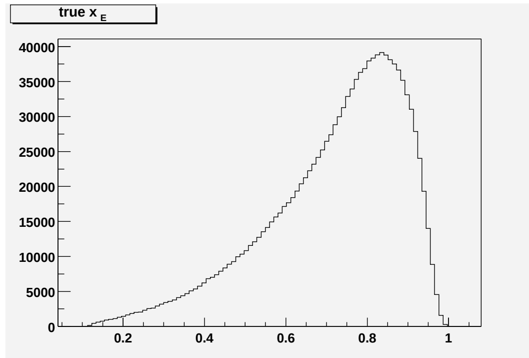
Model-independent description of the B hadron energy spectrum

Cannot take moments from raw measured x_{wd} distribution:

- energy dependent efficiency
- finite detector resolution
- energy dependent reconstruction bias

reconstruction of the true energy distribution by unfolding



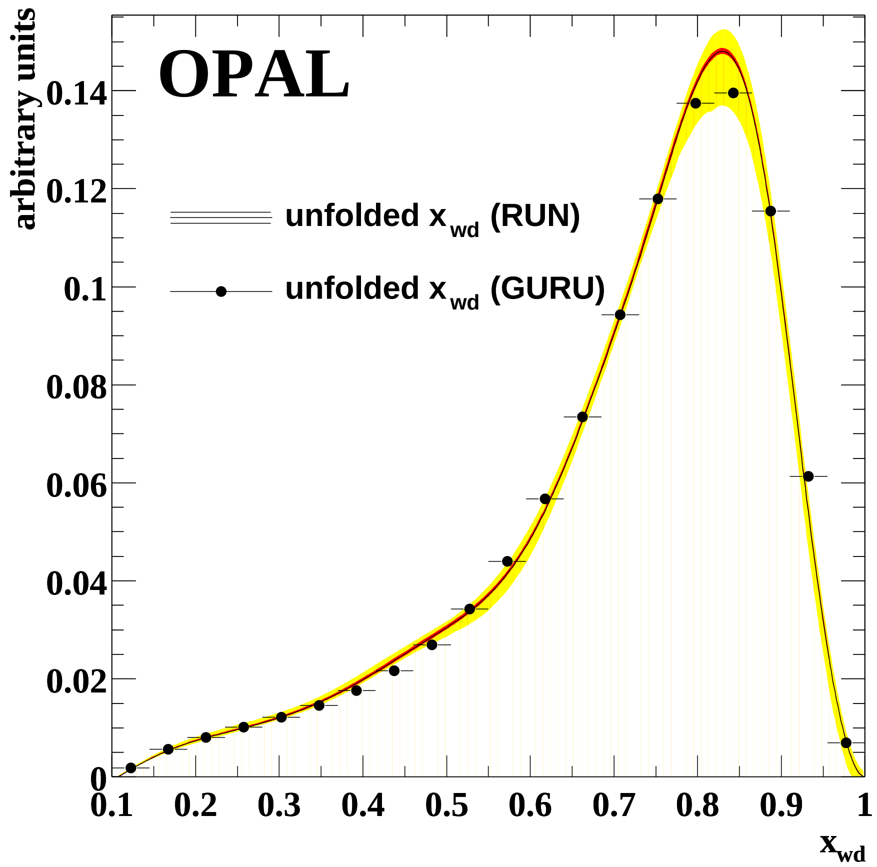


unfolding algorithms: RUN (Blobel), SVD-GURU (Kartvelishvili, Hocker)

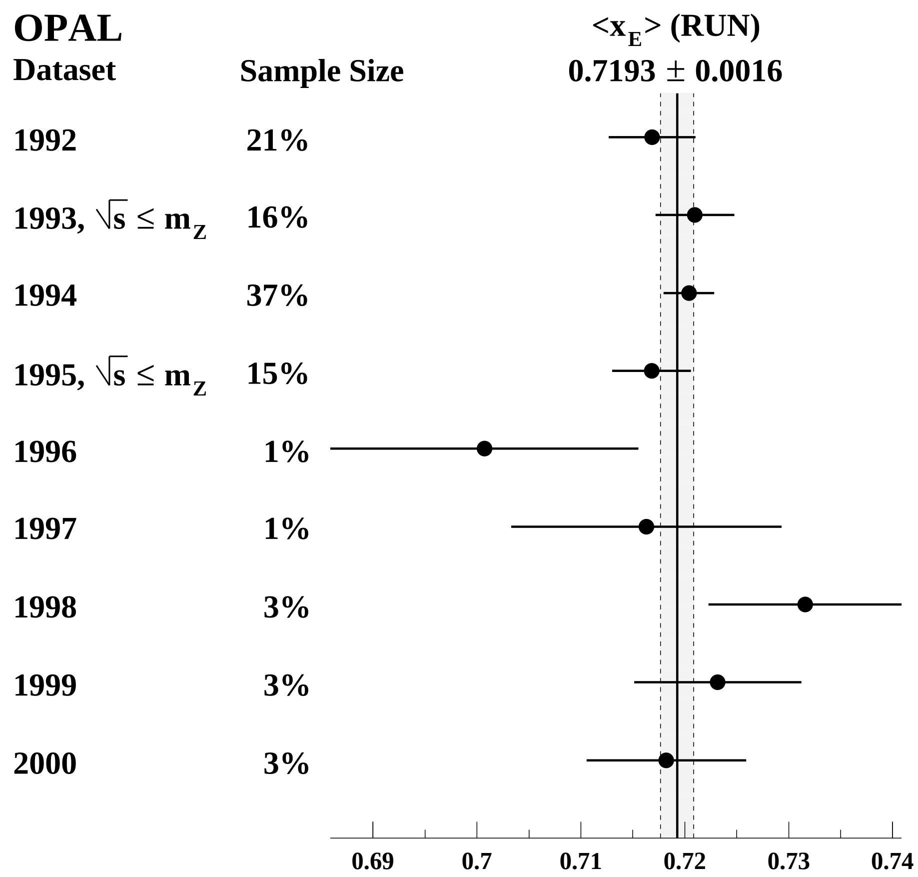
(DELPHI, OPAL) (≈ALEPH, OPAL, ≈SLD)

Unfolded scaled energy distribution (OPAL)

unfolded energy distribution with error band



subsample consistency check



Unfolding result (OPAL)

mean scaled energy of weakly decaying B hadrons:

$$\langle x_{wd} \rangle = 0.7193 \pm 0.0016(stat)^{+0.0036}_{-0.0029}(syst)$$

dominant systematic uncertainties:

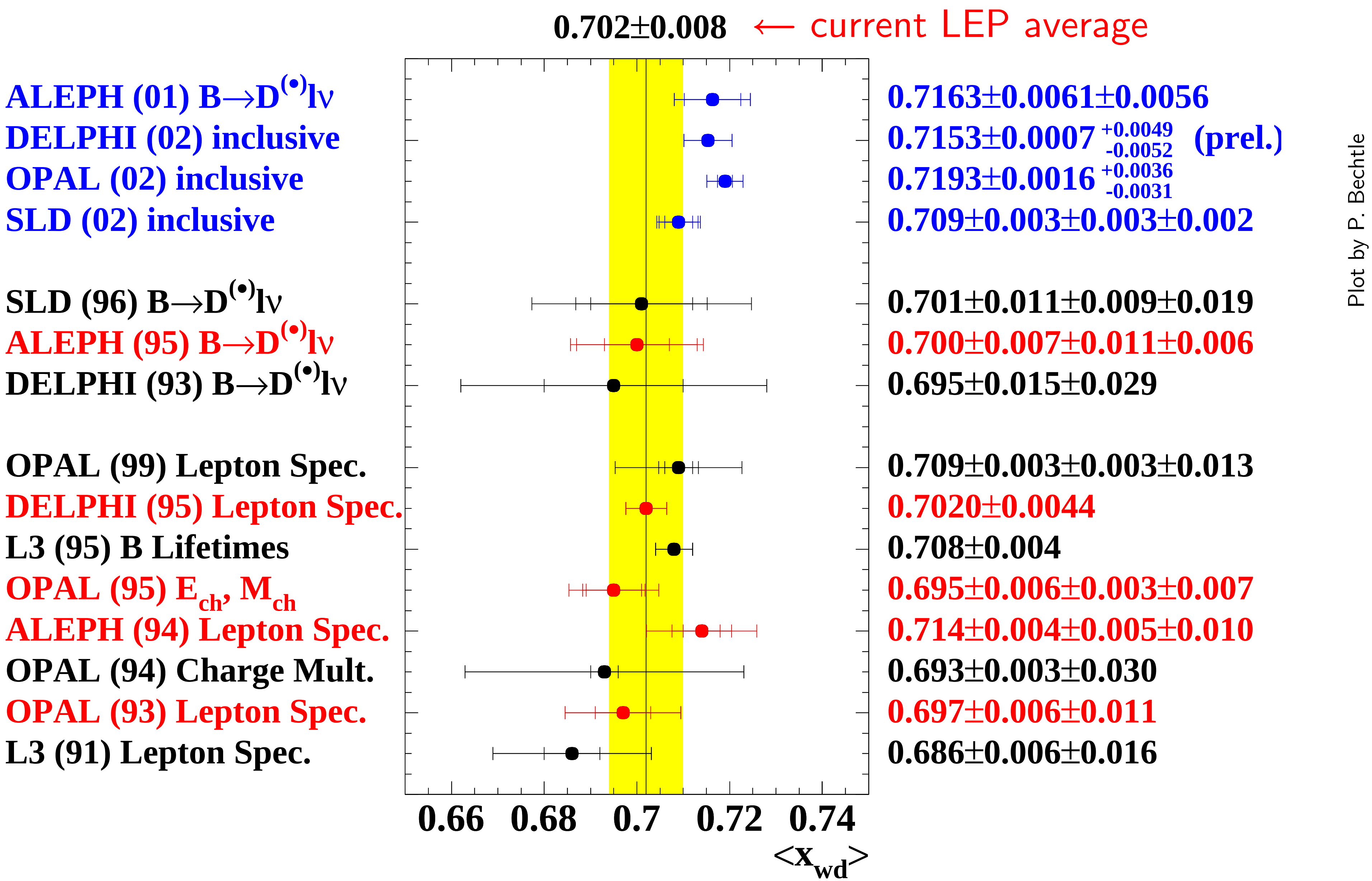
— detector resolution modeling (mainly calorimeter)
— unfolding with different MC types (detector simulation!)

very good agreement
with second unfolding method
$(\langle x_{wd} \rangle = 0.7195 \pm 0.0015(stat))$

good agreement with model fit results

Bowler	$0.7207 \pm 0.0008 \pm 0.0028$,
Lund symmetric	$0.7200 \pm 0.0008 \pm 0.0028$,
Kartvelishvili et al.	$0.7151 \pm 0.0006 \pm 0.0021$

Overview of $\langle x_{wd} \rangle$ measurements



Moments of the energy distribution

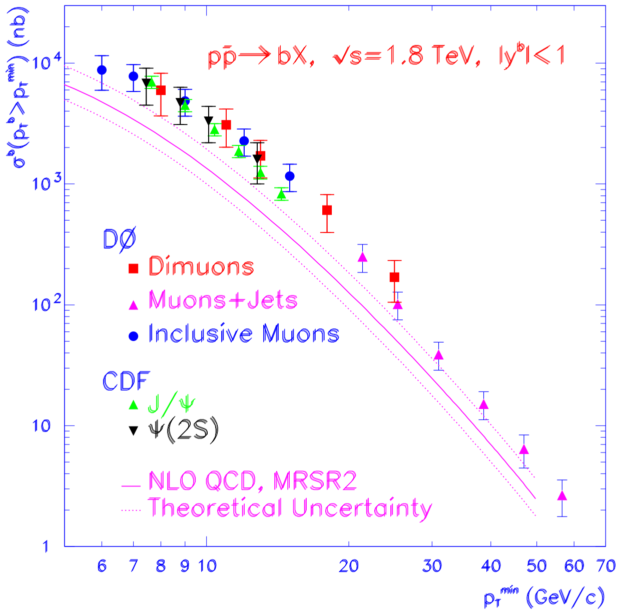
values from *very* preliminary LEP/SLD combination (P. Roudeau, E. Ben Haim):

$$\begin{aligned} D_1 &= 1 \text{ (definition)} \\ \langle x_{wd} \rangle = D_2 &= 0.7151 \pm 0.0025 \\ D_3 &= 0.5426 \pm 0.0012 \\ D_4 &= 0.4268 \pm 0.0010 \\ D_5 &= 0.3440 \pm 0.0017 \end{aligned}$$

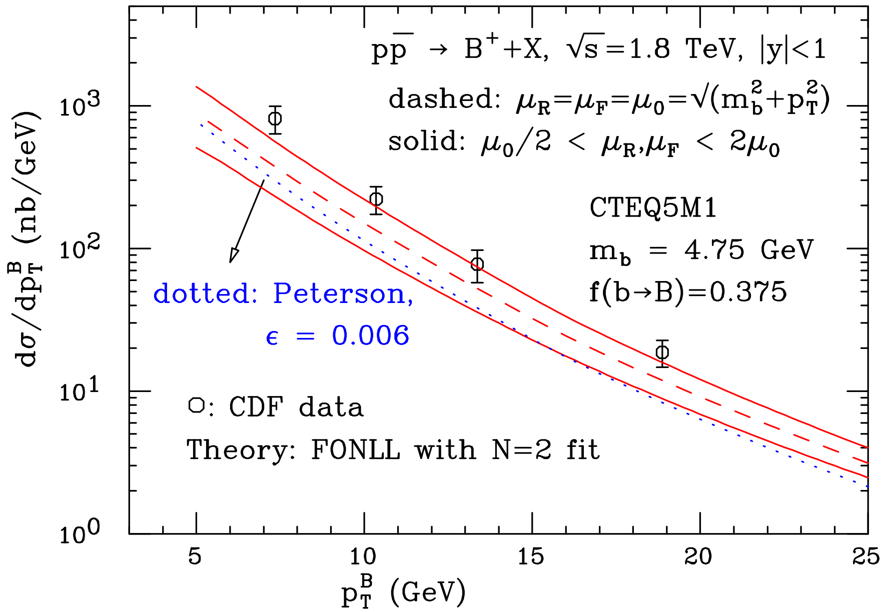
➡ back to Tevatron!

Cacciari/Nason fit to fragmentation function

before



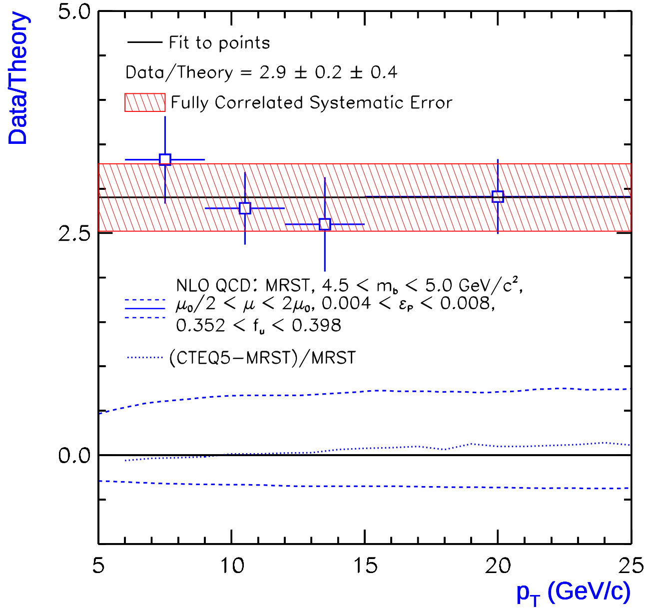
after



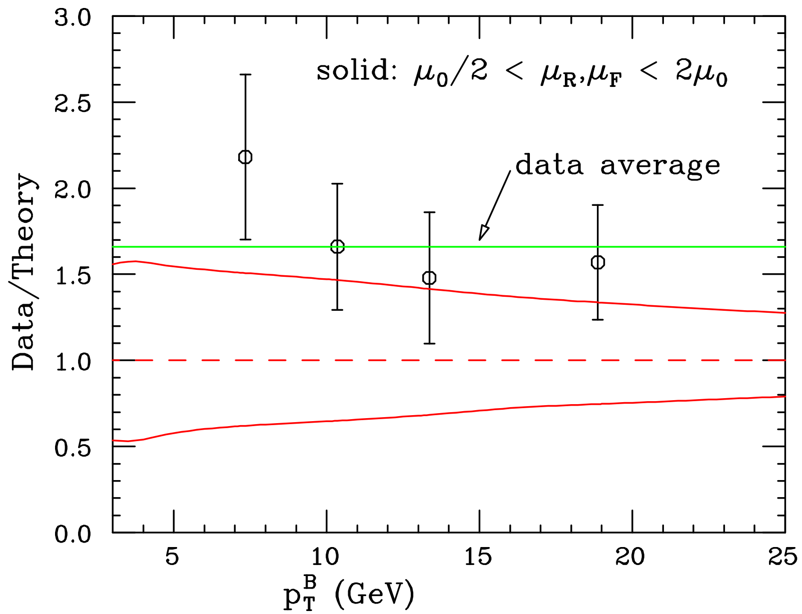
...unfortunately not yet using the new LEP/SLD results
(which will make the prediction slightly larger)

Cacciari/Nason fit to fragmentation function

before



after



Ratio of data and theory reduced from 2.9 to 1.7

...unfortunately not yet using the new LEP/SLD results
(which will make the prediction slightly larger)

Summary

- LEP/SLD are collecting their final b hadronization measurements
- results compatible with older analyses, but much more precise
- hadronization models can be clearly distinguished for the first time
- Tevatron: agreement between b cross-section prediction and measurement

if these results are applied correctly

➡ better have a e^+e^- machine complementing your favourite hadron collider!
(This was the obligatory statement on a next generation linear collider.)